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PAVEMENT MARKING TYPES AND APPLICATION

by

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13. ABSTRACT *(Maximum 200 words)*

This report describes the Facilities Engineering Application Project, "Pavement Marking" conducted from FY 88 to FY 90 at Fort Bragg, NC, and Fort Lewis, WA. A brief description of various pavement marking types is provided along with different considerations used when selecting a marking type. Several pavement preparation techniques and marking application procedures are also outlined. The report highlights the fact that there is no one type of marking, surface preparation, or application technique that will ensure long lasting delineation for every situation.

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PREFACE

This project was sponsored by the Headquarters, US Army Corps of Engineers, as part of the O&M,A Program, Facilities Engineering Application Program (FEAP) from FY 88 through FY 90. The project was conducted by the Geotechnical Laboratory (GL) of the US Army Engineer Waterways Experiment Station (WES).

The project was conducted under the general supervision of Dr. W. F. Marcuson III, Chief, GL, WES, and under the direct supervision of Mr. H. H. Ulery, Jr., Chief, Pavement Systems Division (PSD), GL; and Dr. R. S. Rollings, former Chief, Materials Research and Construction Technology (MR&CT). The WES FEAP Manager was Mr. R. C. Ahlrich and the current WES FEAP Manager is Mr. R. H. Grau. The WES Principal Investigator was Mr. L. N. Lynch who also wrote the report.

The FY 88 demonstration site was Fort Bragg, NC. The points of contact at Fort Bragg were Messrs. R. Harris and T. J. Barnes of the Directorate of Engineering and Housing (DEH), Engineering Planning Service Branch. Mr. L. Ennis of the Engineering Construction Inspection Branch was responsible for inspecting the project.

The FY 89 demonstration site was Fort Lewis, WA. The point of contact was Mr. M. Schoch of the DEH, Master Planning Branch. The work at Fort Lewis was performed in-house by the DEH paint shop. Photographic support was provided by Messrs. D. E. Ray and J. Danczyk, Visual Production Center, Information Technology Laboratory.

COL Larry B. Fulton, EN, was Commander and Director of WES. Dr. Robert W. Whalin was Technical Director.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
degrees (angle)	0.01745329	radians
Fahrenheit degrees	5/9	Celsius degrees or Kelvins*
pounds (force) per square inch	6.894757	kilopascals
gallons (US liquid)	3.785412	cubic decimetres
tons (2,000 pounds, mass)	907.1847	kilograms

* To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: $C = (5/9)(F - 32)$. To obtain Kelvin (K) readings, use: $K = (5/9)(F - 32) + 273.15$.

PAVEMENT MARKING TYPES AND APPLICATION

PART I: INTRODUCTION

Background

1. Pavement markings provide two very essential roles in every pavement system regardless of whether the pavement system is an airfield, a highway, a roadway, or a grocery store parking lot. The pavement markings are designed to improve traffic flow and increase traffic and pedestrian safety. Traffic markings provide directional guidance as the means of improving traffic flow, and regulatory and warning information provided by the markings improve safety.

2. It has been estimated that over 37,000,000 gal of traffic paint, 55,000 tons of pavement thermoplastics, 130,000 tons of glass beads, and an unknown quantity of raised, recessed, thermosetting and tape markings are used annually in the United States (National Cooperative Highway Research Program 1988a). A great percentage of the pavement markings used annually are used to remark faded or failed areas or areas that have insufficient delineation.

3. Pavement marking failures can be attributed to one of several factors; however, the ones that can be controlled by field personnel are the pavement surface preparation and marking application procedures. This report discusses surface preparation and the application of markings as well as provide generalized physical characteristics and performance information of the various types of markings.

4. Several states have performed field performance evaluations which present conflicting results. The conflicting results indicate that a material and pavement preparation or marker application procedure that provides acceptable results in one state, county, or city may provide totally unacceptable results when used in another area. The differences in climate, pavement substrate, and environmental constraints explain why each state and city agency has its own specifications and practices for materials and application procedures. Regulations concerning color, shape, spacing, widths, and reflectance requirements for nonairfield pavement marking applications are provided in "Manual on Uniform Traffic Control Devices" (US Department of Transportation

1988). Technical Manual TM 5-823-4 (Headquarters, Department of the Army 1987) provides this information for US Army airfields, and AFR 88-16 (Headquarters, Department of the Air Force 1988) provides this information for US Air Force airfields.

Purpose

5. The purpose of this report is to present and discuss the proper procedures for applying various types of pavement markings and provide physical characteristics of each type of material. A brief literature search was also conducted to obtain general performance characteristics of the different pavement markings. The pavement markings which are discussed in this report include:

a. Reflective paints.

b. Thermoplastics.

c. Reflective tapes.

d. Raised reflective markers.

PART II: PAVEMENT MARKING MATERIALS

Marker Selection

6. The two question most often posed concerning pavement markings during this study were "Which marker is the best?" and "Which marker should we use?"

7. There are no clear answers to these questions as evidenced by the pavement marking evaluations conducted by various state agencies. The evaluations indicate that a given marker may perform satisfactorily for several years in a particular application under certain climatic conditions and deteriorate quickly in another application or in a different climate.

8. Each type of marking material has advantages and disadvantages; therefore, several items must be considered before the best marker for a given application can be selected. The items which must be considered are:

- a. Climatic region.
- b. Cost of marking versus expected life.
- c. Location and function of the marking on the pavement.
- d. Average daily traffic (ADT) and type of traffic.
- e. Pavement type.
- f. Availability of equipment and labor.

Each of these items are interrelated and must be considered as a group instead of individually. The most critical item from the list will vary with each user agency.

9. The climatic region in which the marker will be used can have a great impact on the selection criteria. For example, in warmer regions some thermoplastics may become unstable due to high pavement temperatures, and some binder materials in markers rapidly deteriorate when exposed to ultraviolet radiation. At the opposite extreme, in cold climates marking materials may become brittle and crack as temperatures drop. Another cold climate consideration is the effect of snow plows on markings. As snow is removed from a pavement, a snow plow blade can remove thick pavement markers in addition to the snow.

10. Some of the more durable pavement markings have a higher initial cost; therefore, they are not normally considered for application by some agencies. However, life cycle and maintenance costs should be considered in

selecting the type of pavement marking. Unfortunately, the availability of funding is often the limiting factor which requires a less expensive initial cost material to be selected.

11. The function of the markers (center line, fog line or edge line, stop bar, and cross walk), affects selection criteria. A center-line marker receives much more abrasion due to traffic than a fog line; therefore, a more durable material is required for the center line. Stop bars and cross walks are abraded by normal moving traffic but are also abraded by the acceleration and braking action of traffic. If the markers are not adequately bonded to the pavement, traffic movement can cause tapes and thermoplastics to become deformed and damaged.

12. It is logical to expect that the number of vehicles or ADT and the type of traffic to which a marking is exposed will be a vital consideration in selecting a marker. A more durable marking is required for larger ADT's and for areas that are exposed to tracked traffic, (i.e., tanks and heavy equipment) while a less durable marking may be considered for rural roads.

13. Once the above "items of consideration" have been examined and understood, the advantages and disadvantages of each marker type should be examined. Since each type of marker will perform differently, the best method of selecting pavement markings is through the use of test sections. The local state Department of Transportation (DOT) normally has performance evaluations of various materials that have been used on state projects. Specific advantages and disadvantages are discussed in later sections.

14. In considering the original question of "what works best," a questionnaire survey was conducted by "Better Roads" (1989) which had approximately 200 readers to respond. One question asked was "which materials actually used by the responding department performed the best in all applications?" Approximately 32 percent stated that traffic paints performed the best for all applications, 30 percent stated that preformed tapes performed the best, and 28 percent stated thermoplastics performed the best. Another question asked, "which material does the responding agency believe performs the best?" This question did not limit the selection to materials used by the agency. Approximately 37 percent of those who responded believed that thermoplastics performed the best, and paints and preformed tapes received considerable lower percentages, 20 percent and 15 percent,

respecti-ly. This survey reiterates the fact that no one material either performs or is perceived to perform the best in all situations.

15. If a particular material cannot be selected to perform well in all situations, what can be done to get the most out of a material once it is selected? To ensure maximum performance of a given marker, it is imperative that the material be placed under ideal conditions.

Traffic Paints

16. Paints, first used in Michigan about 1911 (Organization for Economic Cooperation and Development, Road Research 1975), have been used longer than any other material for marking pavements and exceed all other materials combined in roadway mile usage. Because of the wide use of paints, they are the cost and performance standard used to compare all other marking types.

17. There are several methods that may be employed to classify paints. The paints may be classified by reflectance (reflective or nonreflective), method of application (hot or cold), type of base material, or drying time. The reflectance classification indicates whether a reflective media has been added to enhance delineation. There are four base materials from which a paint is normally manufactured. These four base materials yield four classifications. The four base materials include alkyd resin or oil base, rubber base which is usually a chlorinated rubber, drying oil varnish or modified alkyd known as oleoresin, and water based materials (US Department of Transportation 1981). The first three types listed are solventborne which is the most common type of paint used today; however, because of environmental concerns water borne or water based paints are being used to a greater extent.

18. The last classification, drying time, is dependent upon the method of application, the chemical composition, and the pavement temperature. The following categories of drying times are normally used to classify paints (US Department of Transportation 1981):

a. Conventional: drying time ranges from 7 min to several hours. These are cold applied materials and the specific drying time will be dependent upon atmospheric conditions, film thickness, and road condition.

b. Fast dry: obtain no-track condition within 2 to 7 min. These materials are normally hot-applied materials.

c. Quick dry: obtain a no-track condition within 30 to 120 sec. These materials are hot applied.

d. Instant dry: obtain a no-track condition within 30 sec. These materials are heavily bodied, hot-applied paints.

The obvious advantage of faster drying times is the fact that traffic can be allowed on the pavement very soon after application of the paint.

19. Solvent-borne paints normally consist of approximately 25 percent by volume of pigment, extender, and filler; 25 percent by volume of binder; and 50 percent by volume of solvent. The type of pigment used will depend upon the desired color. Titanium dioxide pigment is used for white paints, and lead chromate has been used for yellow paints, both of which are inorganic materials. The use of organic pigments in yellow paint has been investigated in recent years because of the potential health hazards associated with lead chromate. The organic pigments normally are much more expensive than lead chromate and have had a tendency to fade more rapidly than lead chromates.

20. Inert materials such as calcium carbonate and silica products are the most common type of extenders and fillers used in paints, and the binder can be a composition of up to 10 different ingredients. In solvent-borne paints, the most common types of binder and the most cost effective are alkyd resins or chlorinated rubber modified alkyd resins to which antiskinning agents and dryers are added. Each ingredient of the paint plays a determining role in the durability and service life of the paint, but the binder resin is the most critical.

21. The remaining 50 percent of the paint by volume is solvent or thinner which adds nothing to the integrity or service life of the dried paint film. This means that half of each gallon of paint remains on the pavement and the other half evaporates into the air. The solvent is required to improve the sprayability of the paint, and the type of solvent used affects the drying time of the paint. These are important functions, but the idea of paying for a material of which 50 percent does not contribute to the final product and evaporates into the atmosphere has led to the development of higher solids paints (National Cooperative Highway Research Program 1988).

22. Water-borne or water-based paints were introduced for pavement marking several years ago. However, because of their cost, extended drying time and reduced performance as compared to solvent-borne paints, they were not widely accepted. In recent years environmental regulations throughout the

country, particularly California, have produced an increased interest in water based paints.

23. Current water-based paints use acrylic or latex resins and have drying times of approximately 10 min. Lead-free yellow pigmentation systems have been developed for the water based paints, and waterproof glass beads are used. As a result of these developments, California DOT concludes that water-based paints provide a service life equal to or better than solvent-borne paints, provide better bead retention, and have safer application characteristics than solvent-borne paints (National Cooperative Highway Research Program 1988). However, other agencies have not been as satisfied with these paints as California.

24. One advantage of solvent-borne traffic paints is that pavement preparation is not as critical for their performance as with other types of markers such as thermoplastics. The solvent in the paint reduces its viscosity and surface tension, allowing it to penetrate the road film and bond to the pavement better than some other markings.

Thermoplastics

25. Thermoplastics for use as pavement markings were developed before World War II (National Cooperative Highway Research Program 1988). Thermoplastics are solid at ambient temperature and liquid at elevated temperatures. Thermoplastics do not contain solvents which give them a distinct environmental advantage over solvent-borne traffic paints. Currently, thermoplastics use alkyd or hydrocarbon resins as the base material. Both of these base materials have very similar physical properties; therefore, the selection of one versus the other is largely based on economics.

26. A typical pavement marking thermoplastic consists of approximately 18 percent by weight of resin, 25 percent glass beads, and 57 percent pigment and filler (National Cooperative Highway Research Program 1988). These materials are normally supplied in one of two forms. One form is a premixed material where the manufacturer melts the ingredient materials, blends them together, casts the thermoplastic into blocks, and allows the blocks to cool. The blocks are sold to the user who reheats the material and applies it to the pavement. The second and most commonly supplied form is a granulated mixture. The manufacturer dry blends the required materials together and bags the

blended material. The bags are sold to the user who dumps the bags into the melter for application to the pavement. The granulated material is less expensive since the manufacturer does not have the added cost of melting and blending.

27. Thermoplastics have proven to provide better delineation or lane marking visibility, especially on rainy nights, and have a longer life in warmer climates than do paints (US Department of Transportation 1976). However, their durability in colder regions has been a cause for concern.

28. One possible disadvantage of thermoplastics is the fact that some type of surface treatment or primer is often required to improve adhesion. The pavement surface preparation is a critical element in obtaining a long lasting thermoplastic marker.

Reflective Beads

29. Traffic paints and thermoplastics are not reflective unless a reflectorizing substance is added. During the daytime or in well lighted areas, reflective markings may not be essential. At night during rainy or foggy weather and in areas that are not well lighted, reflective markings are a critical safety aspect for traffic movement. The head lights of vehicular traffic shines on the reflective media; a portion of that light is redirected toward the driver to delineating the driving lane or providing a warning signal.

30. Glass beads are currently the best system available to produce a reflective paint or thermoplastic because they provide two essential properties to refract and redirect light. The two properties are transparency and roundness. Transparency and roundness explain why light is reflected, but other characteristics determine the amount of light reflected. The amount of light reflected is dependent upon the number of beads in the pavement marking, the size and shape of the beads, the surface characteristics of the individual beads, and the index of refraction (US Department of Transportation 1981).

31. The number of glass beads available to reflect light is an obvious factor in determining the amount of reflective light. The greater the amount of reflective media available to the light source the greater the amount of reflection.

32. To understand why shape and surface characteristics are important, it is helpful to understand how transparency and roundness affect reflectivity. Transparency is an important characteristic because the light must pass into the bead before it can be reflected. If the surface is irregular or pitted, the light cannot easily enter the bead. If no light enters, none is reflected. The roundness characteristic causes the entering light to be bent or refracted to a portion of the bead that is imbedded into the paint. The light bounces off of the paint coated portion of the bead and is directed back along the entry path similar to the way in which a mirror reflects light (US Department of Transportation 1981).

33. The size range or gradation of beads used with paints or thermoplastics plays an important role in both immediate and long term reflectivity. One study indicates that the maximum reflectivity is obtained when approximately 50 percent of the bead diameter is embedded into the marking material. Based on this fact, it would appear that a uniform bead size of twice the marking thickness should be selected. However, as pavement markings age, beads and marking material are abraded. As a result of abrasion, beads are dislodged from the marking material reducing the reflectivity. To compensate for wear and abrasion, a gradation band of beads is selected. Large beads are used to provide immediate reflectivity, and smaller beads are used to provide long term reflectivity. As larger diameter beads are dislodged, the smaller diameter beads are exposed and delineate the marked area. There is not a general consensus on the exact gradation that should be used for pavement markings; however, a typical gradation ranges from No. 20 sieve to No. 100 sieve size.

34. A factor that regulates the degree of brightness is the refractive index (RI). The glass bead functions as a light-focusing lens. Like a lens, the bead has a definite focal point. The focal point of a bead is a point outside the bead diameter from which the light appears to originate as it is reflected back towards the source. The position of the focal point is determined by the chemical composition of the glass bead, and the closer the focal point is to the back surface of the bead, the brighter the reflected light (US Department of Transportation 1981).

35. Beads used in traffic paints normally have an RI of 1.50, while those used in thermoplastics normally have an RI of 1.65. Glass beads used in marking airfields normally have an RI of 1.90. For comparison, the focal

point of a bead with an RI of 1.50 is further behind the surface than one with an RI of 1.65. The RI 1.90 glass bead has a focal point located almost on the surface.

36. Most states use glass beads which have an RI of 1.50 even though beads with an RI of 1.65 or 1.90 are more reflective. The main reason for the use of RI 1.50 beads is economics. The RI 1.50 beads are produced from recycled materials, and they exhibit more chemical stability with less weight (US Department of Transporation 1981) than other beads.

Tapes

37. Pavement marking tapes are preformed materials produced at a factory and shipped to the project site in roll or cut-out legend form. Tapes generally consist of a resin binder, pigment, glass beads, and fillers (Bryden and Gurney 1984). An adhesive may be added to the back of the tape to secure the tape for placement, or the adhesive may be a separate component which is applied to the pavement before the tape is placed on the pavement.

38. Tapes are classified into one of two categories, permanent or temporary. Permanent tapes are generally manufactured from plastic materials, and temporary tapes, those used to detour traffic around construction areas, are usually a foil-backed material. It should be noted that this is a generalization since some foil-backed materials may be durable enough to be used as permanent markers.

39. The use of permanent pavement marking tapes has been increasing in recent years due to improved materials used in manufacturing the tapes and a reduction in the maintenance effort when the tapes are properly applied. An example of reduced maintenance effort is the fact that if a small portion of the tape becomes damaged or loose, maintenance crews can cut out the damaged area, apply the adhesive, and place new tape in a short period of time.

40. The initial cost of tapes are relatively high when compared to other types of markings such as paints, but when properly installed, the life-cycle cost is normally comparable to other markings. Pavement preparation is more critical for the field performance of tapes than some other marker types. For use as temporary markings, tapes are one of the easiest methods available.

Raised Markers

41. Raised pavement markers or "buttons" are generally classified as reflective or nonreflective and are available in a wide variety of shapes, sizes, and types and are made from a wide variety of materials. There are two advantages of raised markers over other types of pavement markings. Both of the advantages are due to the fact that the markers are raised. The first advantage is that as a vehicle passes over the marker, a definite sound is produced which provides the driver with an audio warning as well as a visual warning. The second advantage is better delineation during rain. The raised markers are normally above the water level on the pavement and are therefore visible to the driver.

42. The most widely used nonreflective raised markers are produced from ceramic with a glazed surface. These markers resist abrasion and discoloration due to road film. Reflective raised markers usually are constructed using cube-cornered acrylic lenses, tempered glass lenses, or glass bead lenses mounted in a plastic, ceramic, or metal base (National Cooperative Highway Research Program 1988). The reflective markers are manufactured in white and yellow for traffic lane delineation and are also manufactured in other colors such as red to indicate to the driver not to enter the street or in blue to help fire departments locate fire hydrants at night.

43. When properly applied, raised markers are probably the most durable marker and provide the best night and wet pavement visibility. However, the durability of raised markers is greatly reduced in climates that require snow removal because they can be damaged or scraped off the pavement surface by the plow. Numerous problems have also been associated with the adhesive system used to place the markers on the pavement.

44. Several adhesive systems exist for use with raised makers. The systems range from two-component epoxy mixtures to hot-applied asphalt based materials. Often the manufacturer will recommend a particular system based upon the substrate to which the marker will be applied. For example, when raised markers were first introduced, the majority of adhesive systems were epoxies which become brittle upon curing. These hard epoxies caused flexible pavements to deteriorate under the markers. As traffic would cross the raised marker, the impact of the vehicle tire on the marker would be transferred through the marker/adhesive system into the pavement. Repeated impacts would

cause the marker to become dislodged from flexible pavements by "popping out" a portion of the pavement. To reduce this problem, manufacturers developed the hot-applied asphalt based materials. These materials absorb some of the impact and reduce the damage experienced by the flexible pavement.

Primers

45. To ensure proper bonding of pavement markers such as thermoplastics and tapes, it is often necessary to use a primer to prepare the pavement. The primer used on asphalt concrete pavements is normally a thermosetting adhesive which contains pigment reinforced synthetic rubber and synthetic plastic resin dissolved or dispersed in a solvent. Epoxy resin primers are normally used for portland cement concrete (PCC) pavements. The primer used for a particular marker on a particular pavement type should be the type recommended by the manufacturer.

PART III: PAVEMENT PREPARATION AND MARKER REMOVAL

General

46. The preparation of the pavement surface to be marked is a critical element in obtaining a quality product. The type of equipment required and the procedures employed to prepare the pavement and apply the marker are dependent upon the type of pavement marker being used and the type of pavement to which the marker will be applied. Corps of Engineers Guide Specification (Headquarters, Department of the Army 1987) provides guidance on material specifications as well as pavement preparation and maker application.

47. There are three basic surfaces or substrates to which a new pavement marker may be applied. The first substrate is the old pavement marker or the residue of the old pavement marker (with the exception of raised pavement markers). As a general rule, if the old marker is adhering adequately to the pavement surface then the new marker may be applied to the old marker. This is true only if the old marker is adhering to the pavement surface or, in the case of multiple marking layers, to each other, and the new marker is compatible with the old marker. Often an old marker that is adhering well to the pavement surface makes a better substrate for application of the new marker because the marker to pavement bond has already been achieved.

48. The second type of surface is a bituminous pavement. To further complicate pavement preparation, the bituminous pavement may be new or old. The aggregates in a new bituminous pavement are covered with an oily film created by the bitumen or asphalt used in the mix. This film can prevent the marker from adhering to the pavement. New pavements are also more tender than their aged counterparts. If raised markers are placed on the new pavement, they are often lost due to traffic impacts on the marker causing the pavement under the marker to fail. Based on this information, it would seem desirable to let the pavement age before applying the marker; however, safety concerns required that the pavement be marked as soon as it is completed. To provide a marking that will adhere to new pavement, the surface must be properly prepared (i.e., the oily film removed as described in the following section).

49. The aggregates in older bituminous pavements have often become polished and smooth as a result of traffic. The polished surfaces make it difficult to obtain an adequate bond of the marking material. Film caused by

rain, rubber, and grime are also present on the roadway. This film acts as a barrier to prevent the marker from adhering to the pavement. Some type of preparation must be employed to remove any film buildup and to roughen polished aggregates to allow the new marker to bond to the pavement.

50. The third type of surface is PCC. As with the bituminous pavements, differences are noted between new pavements and old pavements. New PCC pavements will have surface films caused by curing compounds and laitance which can prevent the marker from bonding to the pavement surface. Chemical reactions can also occur between the new pavement and the marker. For example, the alkaline nature of uncured concrete adversely affects alkyl paints causing them to be easily removed during the first big rainstorm (National Cooperative Highway Research Program 1988). Older PCC pavements will have a buildup of road film similar to bituminous pavements. Debris such as grime, tire rubber, and industry and agricultural products deposited on the pavement prevent bonding of the marker to the pavement surface. The marking adheres to the debris instead of the pavement; so when the debris is abraded by traffic or washed off by rain, the marking is also removed. Therefore, the common practice of no surface preparation invites the possibility of premature marking failure.

Techniques

51. Just as there are several types of markers and various types of pavement surfaces, there are several methods that will satisfactorily prepare the pavement surface. The method selected to remove deteriorated markings also varies depending upon the type of marker being removed. The methods of pavement preparation and/or marker removal include the following (National Cooperative Highway Pavement Program 1988; Headquarters, Department of the Army 1987):

- a. Compressed air.
- b. Burning with excess oxygen.
- c. Chemical removal.
- d. Grinding.
- e. Sandblasting.
- f. Water blasting.
- g. Wire brushing.

Compressed air

52. The removal of loose debris on the pavement surface using compressed air is one of the most common methods of pavement preparation. This method is effective in removing loose rocks and dust, but it will not remove an oily asphalt film, road film, or deteriorated markings. This method will provide the most benefit when used in conjunction with other methods.

Burning

53. Burning with excess oxygen is a modification to the old burning methods used to remove deteriorated markings. The old method consisted of burning propane or butane or both with air creating a flame temperature of approximately 2,000°F. The direct flame was placed in contact with the marker causing combustion and removal. Some markers such as paints and thermoplastics contain a large quantity of fillers and noncombustible extenders which require long contact times with the flame. The slow rate of combustion of the markers allows heat from the flame to be absorbed into the pavement. The absorbed heat could result in spalling of PCC pavements and melting of bituminous pavements. By providing excess oxygen through a separate nozzle, the flame temperature is significantly increased, thereby decreasing the time required to burn off the existing marker. The reduction in contact time also reduces the possibility of damaging the pavement. Once the marker has been burned, a residue of inert combustion products will remain on the pavement surface. The residue can normally be removed by sweeping or wire brushing. This method has been found effective in removing old marking films up to 20 mils thick and can remove foil tapes that have been exposed to traffic. As marker thicknesses increase above 20 mils, the method becomes less effective and other methods of removal should be considered (National Cooperative Highway Research Program 1988). Extreme care must be used during the operation of this equipment to ensure that the flame does not remain stationary too long. The excessive heat can easily damage pavements if the equipment is used improperly.

Chemical removal

54. The use of chemicals as both a marker removal method and a pavement preparation method has been found to be very effective. In a Louisiana project (National Cooperative Highway Research Program 1988), chemical cleaning of PCC pavements was shown to increase the life of pavement markers by enhancing their adhesion to the pavement. The chemical, a 3 percent hydrofluoric acid

solution, was sprayed onto the area to be marked, allowed to react, and was then washed off with water. The pavement surface was allowed to dry before the markers were applied. As one would expect, this method is more expensive and more hazardous than some of the other methods. Particular hazards include exposure of personnel to the acid solution, possible damage to vehicles that come in contact with the area before the acid has been removed, and exposure of the environment to the acid solution when it is washed off the pavement.

55. Pavement markings which are 20 mils thick or less can be removed very effectively using chemicals. The method for marker removal is the same as pavement preparation. Even though chemical removal and preparation methods are effective, much care and consideration must be taken before approving a chemical method. With the ever increasing environmental concerns and in an effort to continually improve safety, it is recommended that chemical methods not be used.

Grinding

56. Grinding is a relatively quick method for both pavement preparation and marker removal. As the name implies the grinding process prepares the pavement or removes the existing marker by an abrasive action. The method works well in removing any thickness of pavement marker. The one disadvantage is that it can alter the surface texture and appearance of the pavement surface. This method is not recommended for marker removal if the area will not be remarked. If the area is remarked, alterations to the pavement surface will not be as noticeable since they will be covered up by the new marker. Grinding is not recommended for use when marking an open-graded friction course or rough-textured PCC pavements.

Sandblasting

57. Sandblasting is an effective method of pavement preparation and existing marker removal. In this method the sand is forced in contact with the pavement or the existing marker by compressed air. As the sand impacts the surface, the marker or road film is removed by the abrasive action. The effectiveness of sandblasting in removing existing markers is dependent upon the type of marker and the marker thickness. For example, sandblasting is very slow in removing foil backed taped and has little effect on plastic tapes, but it removes paints and thermoplastics relatively easy. If care is exercised when sandblasting, the marker can be removed without changing the pavement color or texture. The disadvantage of sandblasting is the amount of

equipment required and the fact that used sand is left on the pavement surface. Some areas no longer allow the use of sandblasting because blowing sand and dust may violate atmospheric pollution statues or may drift into areas where it would be objectionable.

Water blasting

58. Water blasting consists of directing a high-pressure water jet at the pavement surface. It can be used for surface preparation or marker removal. A modification to the water blasting technique can be achieved by adding sand to the water. This method is often termed hydroblasting (National Cooperative Highway Research Program 1988). Water blasting and hydroblasting yield similar results to sandblasting except when water blasting is used, the pavement must be allowed to dry before work can continue. The effectiveness of marker or road film removal is dependent upon the thickness of the marker or film being removed and the pressure of the water jet. Normal operating pressures are 2,000 to 10,000 psi.

Wire brushing

59. Wire brushing is one of the simplest methods of surface preparation, but it is not effective in removing existing markers. The effectiveness of wire brushing for pavement preparation is dependent upon the condition of the brushes and the thickness of the road film. Worn brushes will not remove the road film as effectively as new brushes. Therefore, it is important to inspect the brushes on a regular basis to ensure the brushes are performing adequately. "Regular basis" will be dependent upon the type and texture of the pavement and should be determined at the beginning of each project.

60. Regardless of which method or methods are chosen to remove existing markers, it is important to examine the prepared area in the daytime and at night. Often a marker that appears to be removed during daylight hours will be visible under the reflection of headlights at night. Glass beads can be retained very easily in rough textured pavements. The reflection created by the glass beads can create confusion for traffic if the area is being marked in a different pattern. If the area is to be remarked in the same pattern, the remaining glass beads may not create a problem.

61. Another method of removing markings is to simply paint over them using black paint. The effectiveness of this method will be dependent upon the pavement surface and the type marker. For example, when black paint is used to cover markings on a light colored pavement, the black paint may be

highly visible and could be confused with newly placed markings. Also, the black paint can be worn off exposing the original marking. It is recommended that a test section be used before black painting be allowed for wide scale application.

62. Table 1 presents the cost effectiveness of the various pavement preparation and marker removal techniques. This table can be used to provide general guidance when selecting the method or methods to be used for a project.

63. Table 1 indicates that wire brushing is the most cost-effective method of pavement preparation followed by grinding, sandblasting, and water blasting. The significant advantage wire brushing exhibits over the other methods could be greatly reduced as the brushes become worn during use. Burning with excess oxygen is the most cost-effective method of stripe removal followed by sandblasting, grinding, and water blasting. Sandblasting is the most cost effective overall providing good stripe removal and pavement preparation techniques.

64. There is a wide range of equipment used to perform the pavement preparation and stripe removal methods. To determine if the equipment will perform adequately for a given task, it is recommended that a test section be used. Visual inspection of the test section will normally be adequate in determining if the equipment is accomplishing the desired task without damaging the pavement.

Table 1

Relative Cost Effectiveness of Various Surface Preparation and Stripe Removal Methods*

	Surface Preparation			Stripe Removal		
Method	Cost**	Effectiveness†	Cost/ Effectiveness	Cost**	Effectiveness†	Cost/ Effectiveness
Blowing	01	0.05	20.0	01	0.005	200.0
Burning (excess O_2)	24	2.00	12.0	24	8.000	3.0
Chemical	54	6.00	9.0	54	5.000	10.8
Grinding	36	9.00	4.0	36	6.000	6.0
Sandblasting	52	10.00	5.2	52	10.000	5.2
Water blasting	38	7.00	5.4	38	5.000	7.6
Wire brushing	10	7.00	1.7	10	0.500	20.0

* Taken from National Cooperative Highway Research Program (1988).
** Cost = cents per foot.
† Effectiveness: Does not remove material and/or harms pavement = 0.
Removes material and/or does not harm pavement = 10.

PART IV: MARKER APPLICATION

Equipment

65. The type of equipment and procedures used to apply a traffic marking will be dependent upon the marking type and location (climate region and location on pavement) placed. The recommended thickness of paint and thermoplastic markers and the spacing requirements for skip lines and raised reflective markers are provided in Guide Specification 02577 (Headquarters, Department of the Army 1987) and in "Manual on Uniform Traffic Control Devices" (US Department of Transportation 1988). Safety devices which are required on the marking equipment as well as traffic control guidelines are also provided in "Manual on Uniform Traffic Control Devices".

Traffic paint equipment

66. The equipment used to apply traffic paints can be either self-propelled, towed, or hand-operated as shown in Photos 1, 2, and 3, respectively. Air pressure is the most common method of forcing the paint from the storage tank, atomizing it through a nozzle, and applying it to the pavement surface. The wet-film thickness of the paint will be effected by vehicle speed, paint temperature and viscosity, and the hydraulic head of paint in the storage tank. If the vehicle slows down, the wet-film thickness increases; if it speeds up, the wet-film thickness is reduced.

67. The paint storage tanks on the application equipment should be equipped with mechanical agitators. The agitation will ensure the paint remains homogeneous and will prevent localized hot spots of hot-applied paints. Strainers should also be installed in the paint lines to prevent the nozzles from becoming clogged. Pressure gages should be located in a position to allow easy reading.

Thermoplastic application equipment

68. Thermoplastics may be applied to the pavement surface by spraying techniques or by extrusion. The equipment and techniques used to spray thermoplastics is almost identical to the equipment used for paints. With the extrusion method the molten thermoplastic is poured onto the pavement surface and formed into a line by a shaping die. An example of the shaping die is shown in Photo 4. It is important that either type of equipment, spray or extrusion, continually mix the material to provide homogeneity and to prevent

uneven heating and localized hot spots. An oil bath heating media should be used instead of direct flame heating to further minimize the possibility of uneven heating.

69. The thermoplastic application equipment can be mobile or portable. Mobile thermoplastic application equipment is defined as a truck-mounted, self-contained pavement marking machine. Portable is defined as handoperated equipment designed to apply stop bars, legends, arrows, and short lengths of line (Headquarters, Department of the Army 1987). The portable equipment normally only extrudes material on the pavement but the mobile unit can spray or extrude the material. The normal application temperature for thermoplastics is 375 to 425°F, and the application equipment should be able to maintain this temperature range. Thermometers and gages should be located so that they are easily visible to quality control and operator personnel.

Reflective media dispensers

70. Reflective media or bead dispensers as shown in Photo 5 are attached to the marker application equipment and are operated automatically and simultaneously with the marker applicator. The bead dispensers can be gravity fed or pneumatically fed. The dispenser should be designed to provide uniform coverage over the entire length and width of the stripe. The flow of beads should begin shortly before the application of the stripe and should continue a short distance after the application of the stripe. This technique will ensure that the entire stripe has been covered.

Traffic tape application equipment

71. Mechanical tape application equipment is designed to apply precoated pressure sensitive tapes. The mechanical equipment is usually used to apply center lines, fog lines or edge lines, and stop bars. Legends and arrows are normally placed by hand using hand tools to apply the adhesive to the roadway and seat the marker to the pavement (Photo 6).

Application

72. Once the pavement surface has been prepared and the appropriate primer applied and allowed to cure, the marker is applied to the pavement. The pavement temperature should be 40°F and rising to apply traffic paints and thermoplastics while a pavement temperature of 60 deg and rising is required for preformed tapes. It is important that the pavement surface be free of

moisture when applying the markers. This is especially true when applying thermoplastic markers. The heat of a thermoplastic material will cause moisture to be drawn from the pavement forming blisters and delaminate areas of the thermoplastic. A simple method to determine if the pavement is dry enough to apply a thermoplastic is to place a square piece of plastic or tar paper on the pavement surface and pour a small quantity of thermoplastic onto square. The thermoplastic is allowed to cool, the square is removed from the pavement surface and examined. If the underside of the square does not have any condensation present, then the pavement is dry enough to mark.

73. The application of paints and thermoplastics is simple. The material is sprayed or extruded onto the pavement surface to the thickness specified. The distance of the spray nozzles from the pavement surface must be adjusted to ensure the markers have clean sharp edges. The thickness of sprayed-on markers is adjusted by the speed of the equipment while the thickness of extruded markers is adjusted by a gate on the die.

74. The application of tapes and button markers is also relatively simple, but it may be accomplished using different methods. The materials may be either applied to the pavement surface or recessed into the pavement. In an effort to obtain longer field performance from pavement markers, some state DOT's experimented with recessing or inlaying tapes and buttons. These techniques are no longer experimental and have been used extensively by various DOT's.

75. The most common method of inlaying tape materials is to roll the tape into a flexible pavement as it is being constructed. The edge line and center line markings are carefully placed onto the fresh asphalt cement concrete after initial compaction. As finish rolling is being completed, the tape is inlaid into the pavement by the weight of the roller. Tapes cannot be inlaid on pavements that are already constructed.

76. The most common method of recessing button markers is to grind a small channel into the pavement and place the marker at the bottom of the channel. The channel width and depth are dependent upon the size of marker being used. This method can be used in both PCC and asphalt pavements and increases the life of the marker by eliminating the marker's exposure to traffic. The disadvantage of this method is a reduction in delineation. Since the marker is recessed, it is not as visible, and water can be retained in the channel eliminating the marker's effectiveness in rainy weather.

77. The more common method of applying tapes and button markers is to place them on the pavement surface. Tapes are placed on the pavement surface and seated using hand-rollers. The adhesive used to bond the marker is applied to the pavement surface and then the marker is pressed into the adhesive. A typical method of seating the raised marker is for one member of the crew to step on it after it is placed on the pavement.

PART V: CONCLUSIONS

78. Pavement markings play roles in the safety and efficiency of traffic flow of pavement systems. They improve traffic flow by providing directional information and increase safety by providing warning and regulatory information. There is no one type of marking or type of surface preparation and application technique that will ensure long lasting delineation. The determining factors for marking field performance are as follows:

- a. Abrasion resistance.
- b. Visibility.
- c. Bonding strength to pavement.
- d. Weatherability.

79. Abrasion resistance is a material property that includes the marking's ability to retain reflective media, (if a reflective marking) the marking's ability to resist wear, and the marking's ability to resist becoming dislodged during snow removal operations. Visibility is a material property and a design characteristic. The shape and thickness of preformed markings are examples of material properties that affect visibility. An example of a design characteristic would be placing raised reflective markers into a grove cut into the pavement. This type of design often enhances the length of time a marker will stay in place, but the marker can easily be covered with water during a rain storm. When the water covers the marker, the delineation is greatly reduced. The bonding strength of a marking to the pavement is a material property, a design characteristic, and a workmanship concern. The marking is manufactured to be used in a specific manner and in the case of preformed materials, the bonding mechanism is manufactured with the marking. If there is a defect in the bonding mechanism, the marking will not properly adhere to the pavement. The pavement preparation techniques and marking application procedures have often been refined on a local basis to include climate concerns. These methods must be reviewed and, if acceptable, they must be included in the project specifications. The workmanship concerns are very simple. No matter how well the specifications incorporate pavement preparation and application techniques, or how good the quality of the marking, if the quality of the workmanship is poor, the marking will typically have a short useful field life.

80. To achieve the optimum field performance of a pavement marking, the above-mentioned factors must be balanced. The balance between these factors will vary from location to location depending upon the location climate, the pavement substrate, the function of the marker, and the type and amount of traffic. One material and one set of pavement preparation and application techniques will not perform satisfactorily for all marking needs.

81. Several state agencies have performed field evaluations which monitor pavement preparation, marker application, and field performance of various types of pavement markings. The fact that keeps emerging from the literature search and from the conversations with personnel during the FEAP "Pavement Markings" project is that a research effort is greatly needed to consolidate and compare the field performance findings. After the consolidation and comparison of the available data guidelines for marking selection, pavement preparation and application techniques based on the marking selected should be prepared. The guidelines established from the effort must include recommendations based on differing climatic conditions, ADT's, pavement substrate, and marking location or use on the pavement. Guidelines established through this type of effort and disseminated through civilian specification societies such as ASTM and incorporated into military specifications could improve the performance of all types of pavement markings.

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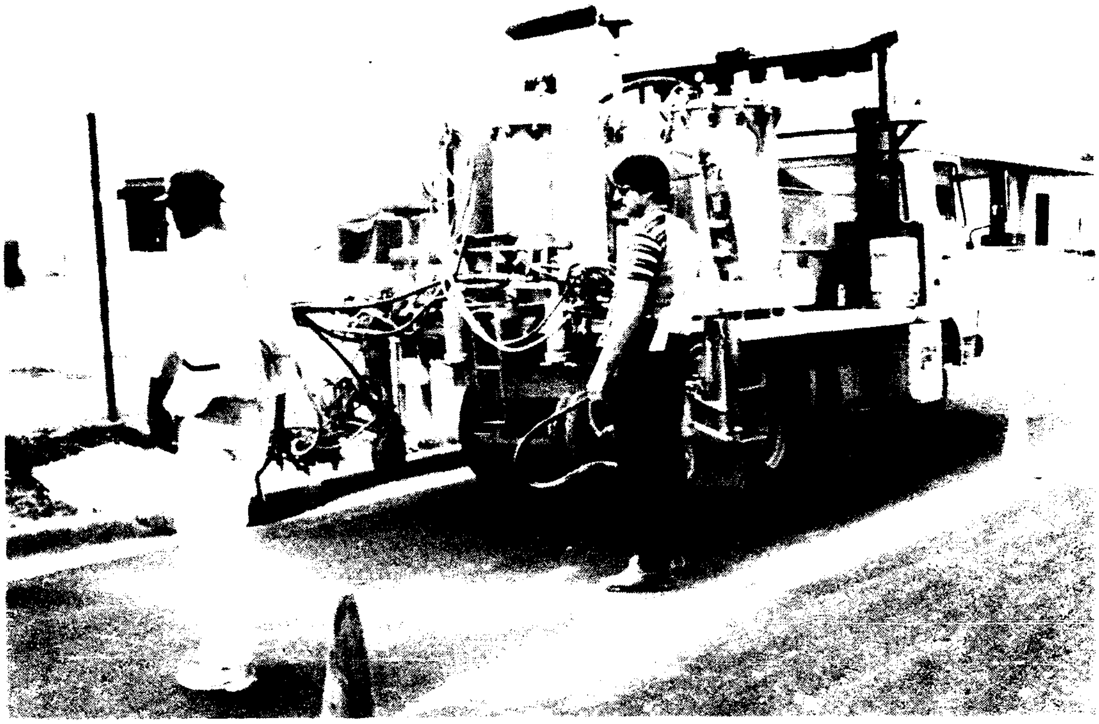

Photo 1. Self-propelled paint applicator

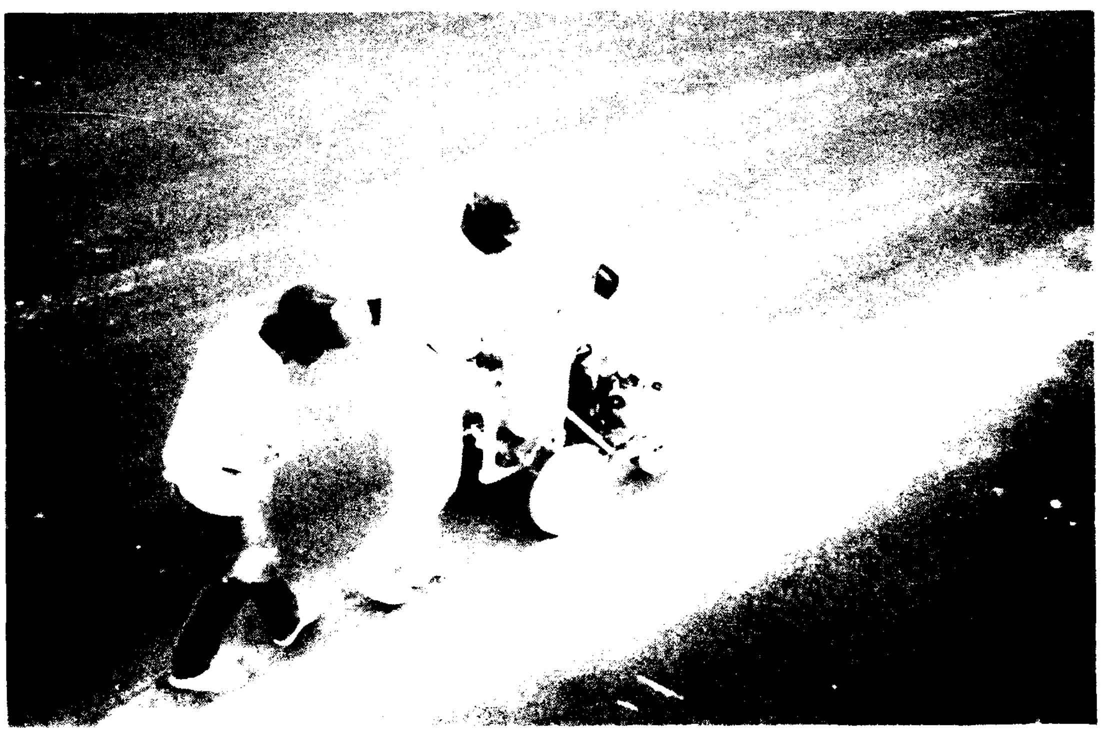

Photo 2. Hand-operated paint applicator

Photo 3. Hand-held paint applicator

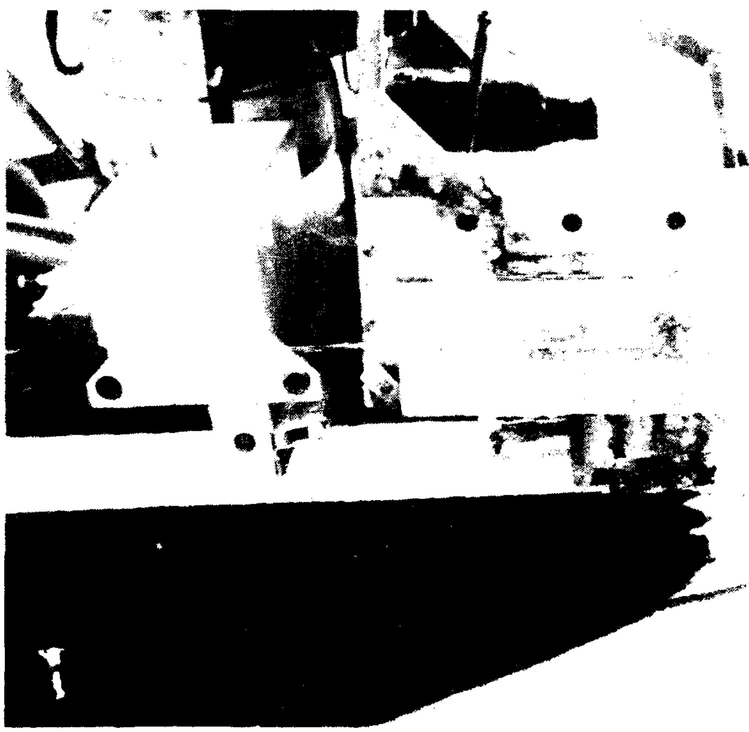

Photo 4. Shaping die used for thermoplastic application

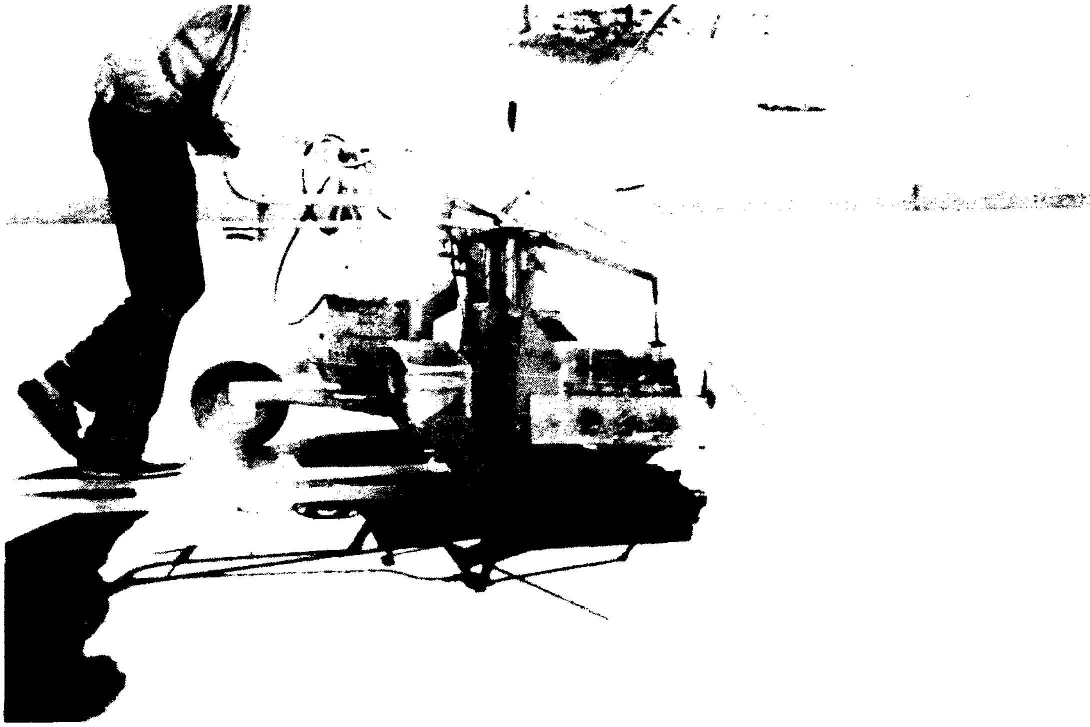

Photo 5. Thermoplastic applicator with bead dispenser on back

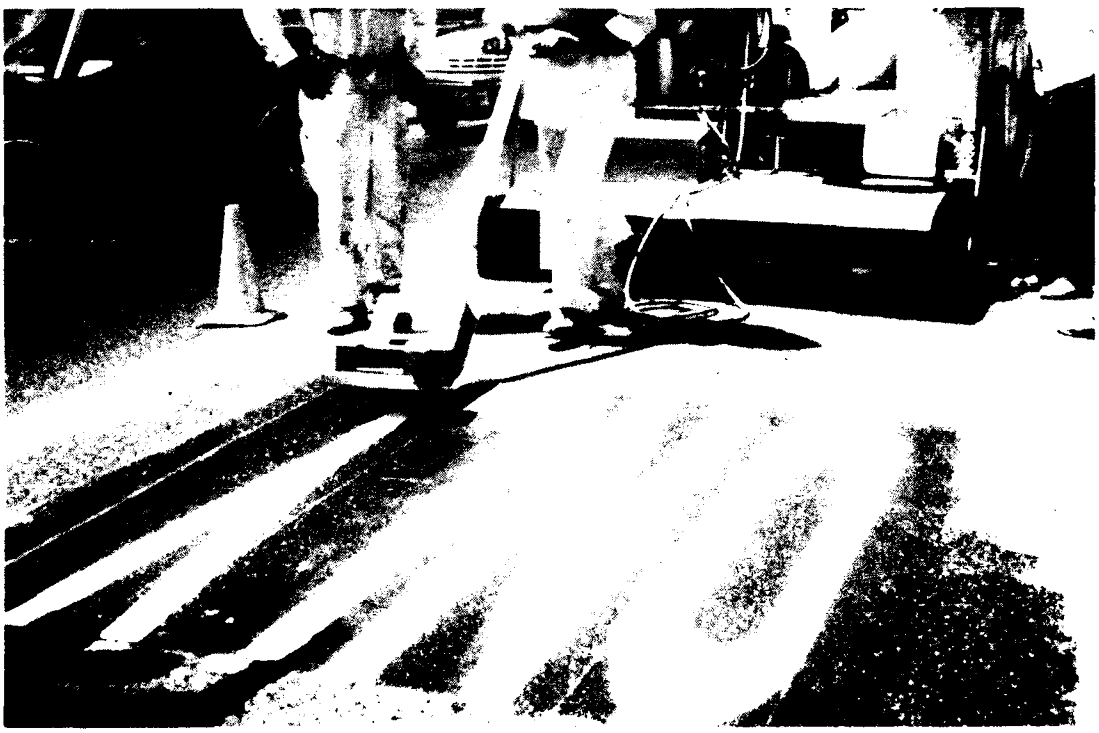

Photo 6. Sealing traffic tape using a 150-lb roller